Soils and Soil Fertility

California Farm Academy, Winters

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Chuck Ingels

UC Cooperative Extension,

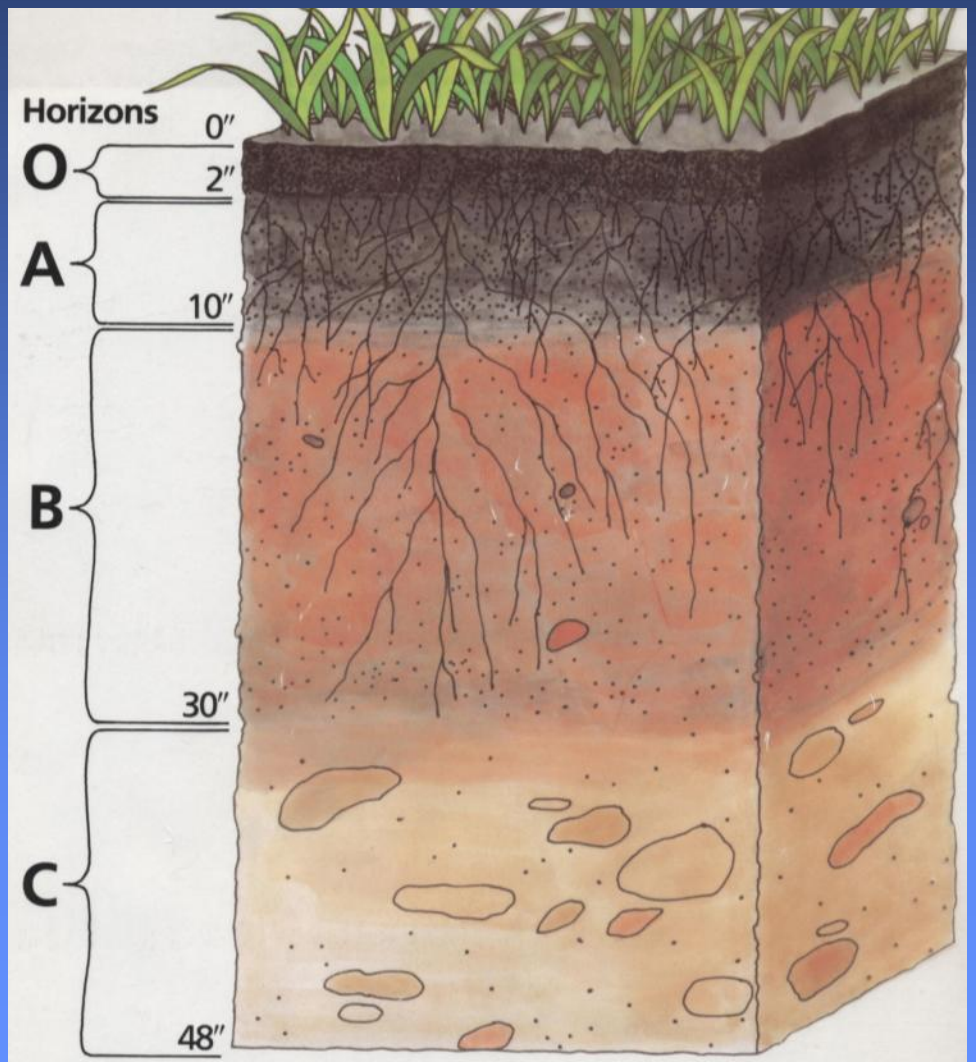
Sacramento County

Topics to Be Covered

- Soil Texture and Structure
- Soil Organic Matter and the Soil Food Web
- Soil Fertility and Plant Nutrition
- Dealing with Soil Compaction and Restrictive Soil Layers

Soil Texture and Structure

A Soil Profile



Litter layer

Biological activity

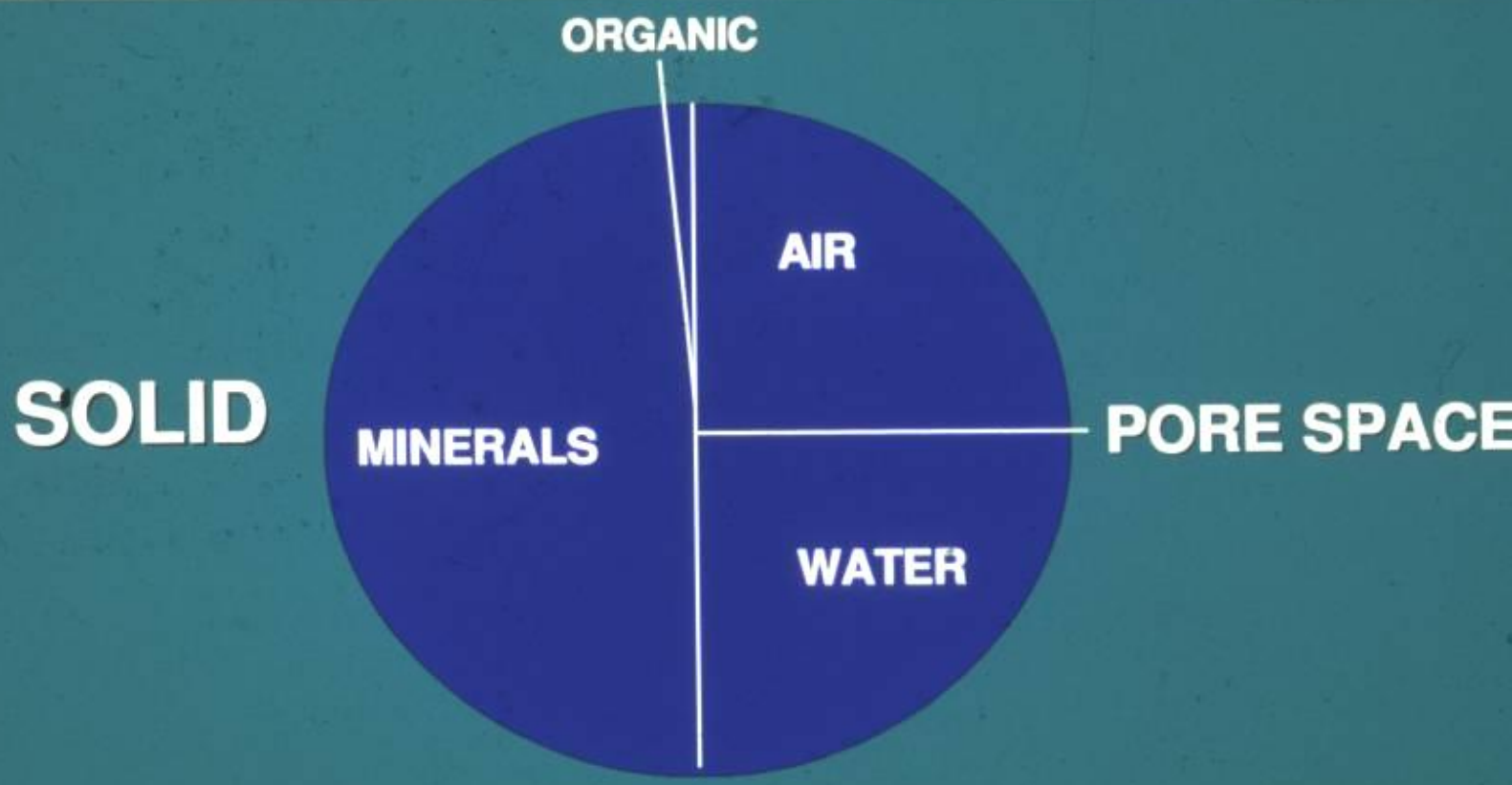
Zone of accumulation (iron, clay, aluminum, and organic compounds)

Parent material

Components of Soil

- Solid particles (sand, silt, clay)
- Soil pores (air, water)
- Soil org. matter, including organisms
- Chemistry (nutrients)

SOILS



Soil Characteristics

Physical Components

- ✓ Texture
- ✓ Structure

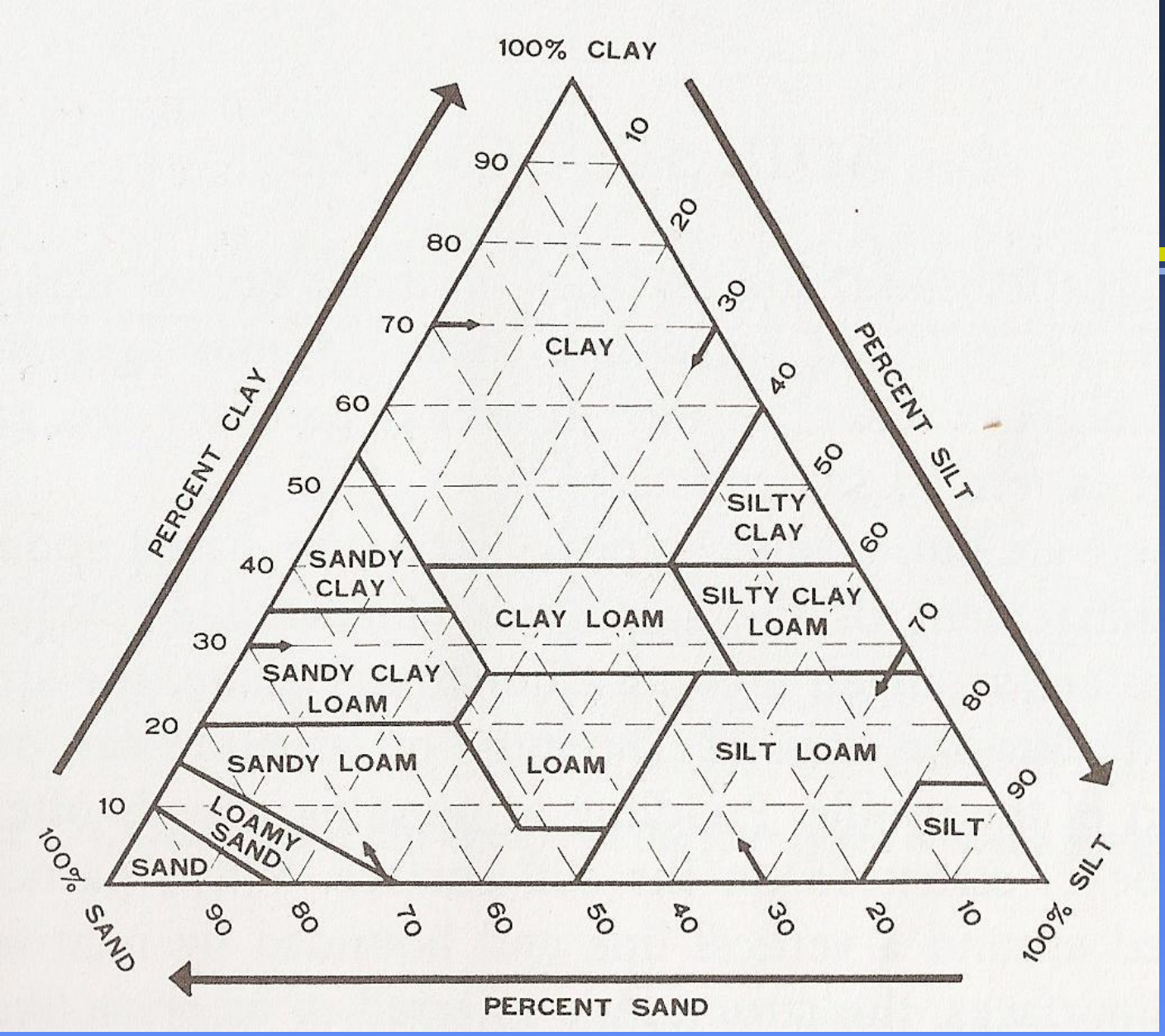
Physical Properties

- ✓ Water infiltration
- ✓ Water holding capacity
- ✓ Nutrient holding capacity
- ✓ Aeration

Soil Texture vs. Structure

- Texture – The percent sand, silt, & clay, based on the soil triangle
  - » e.g., sandy loam, clay loam
- Structure – The arrangement of primary particles into secondary units (aggregates)
  - » Affected by compaction

Soil Texture



The Soil Triangle

CA Farm Academy

Sand: 18%

Silt: 36%

Clay: 46%

Soil Texture

Loamy sand **LIGHT**

Sandy loam

Loam

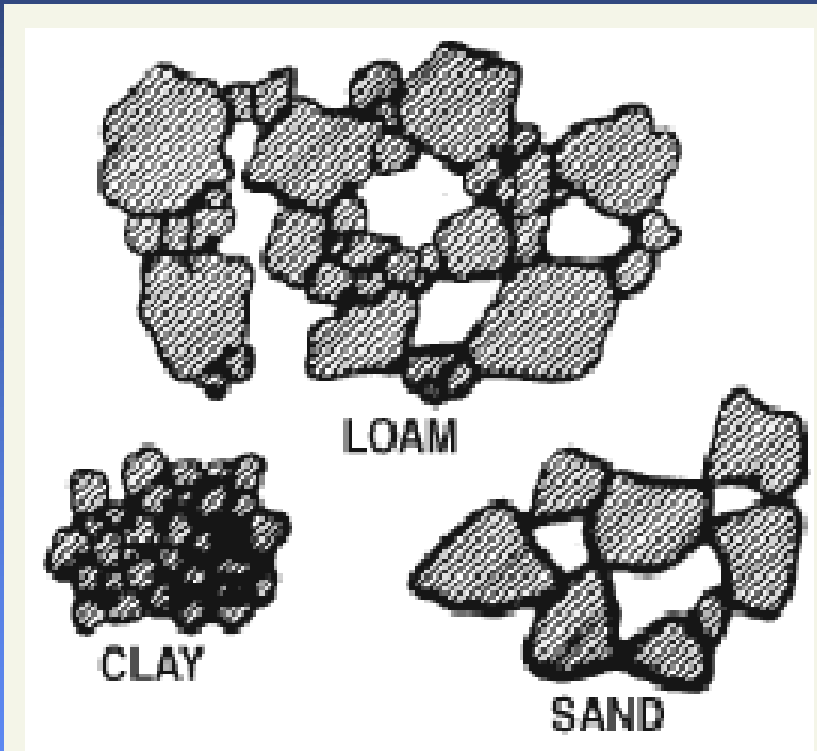
Silty loam

Clay loam

Clay

Silty clay

Sandy clay **HEAVY**

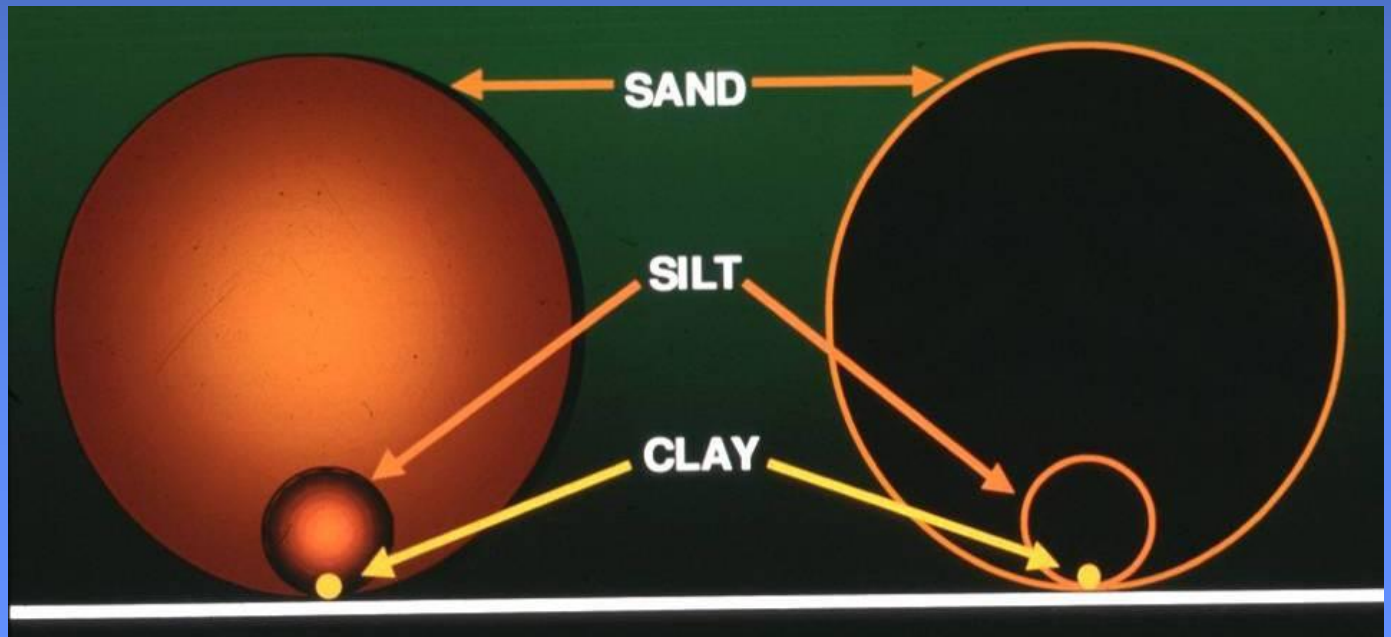


Sandy

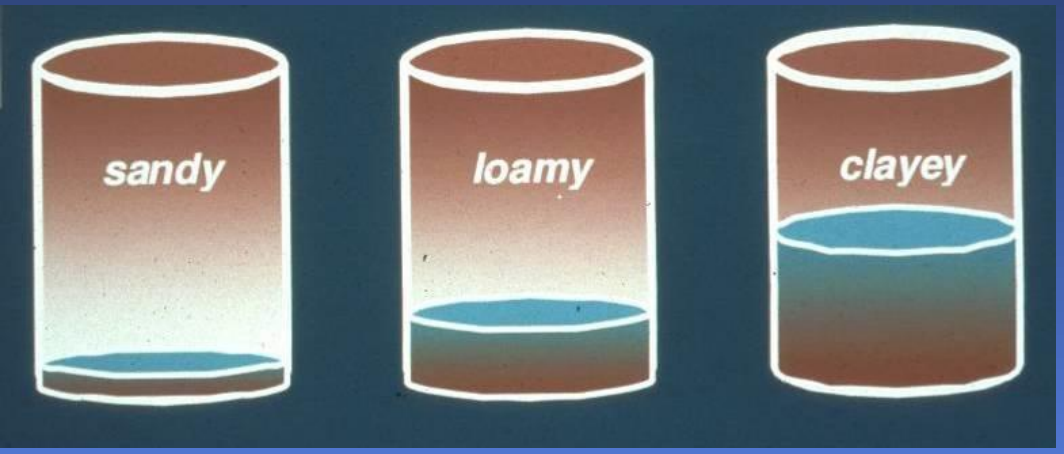
Clayey

Soil Particle Sizes

Sand	2.00 to 0.05 mm
Silt	0.05 to 0.002 mm
Clay	0.002 to <0.0002 mm

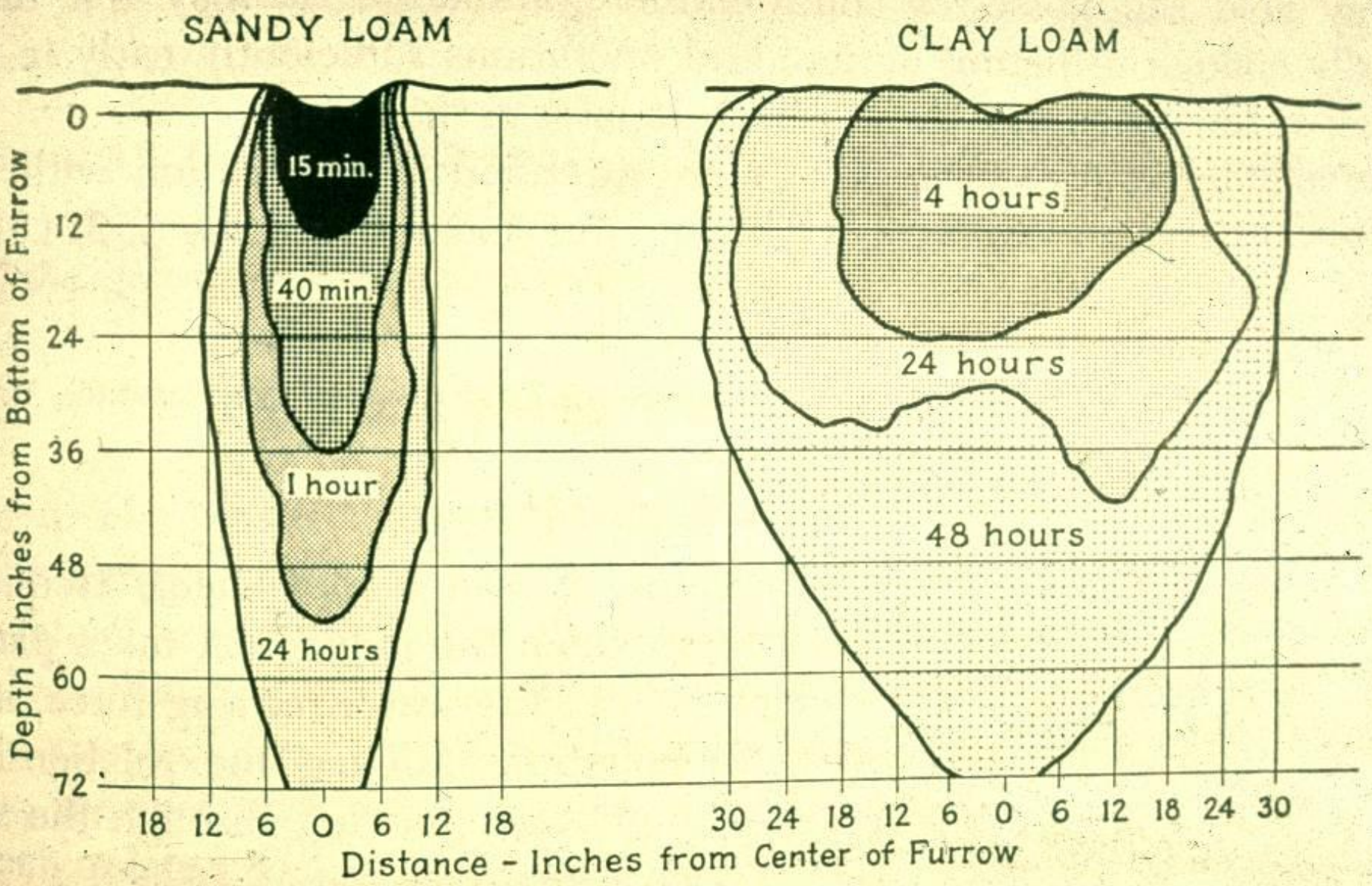


Soil Texture Affects Soil Moisture



Water Holding Capacity

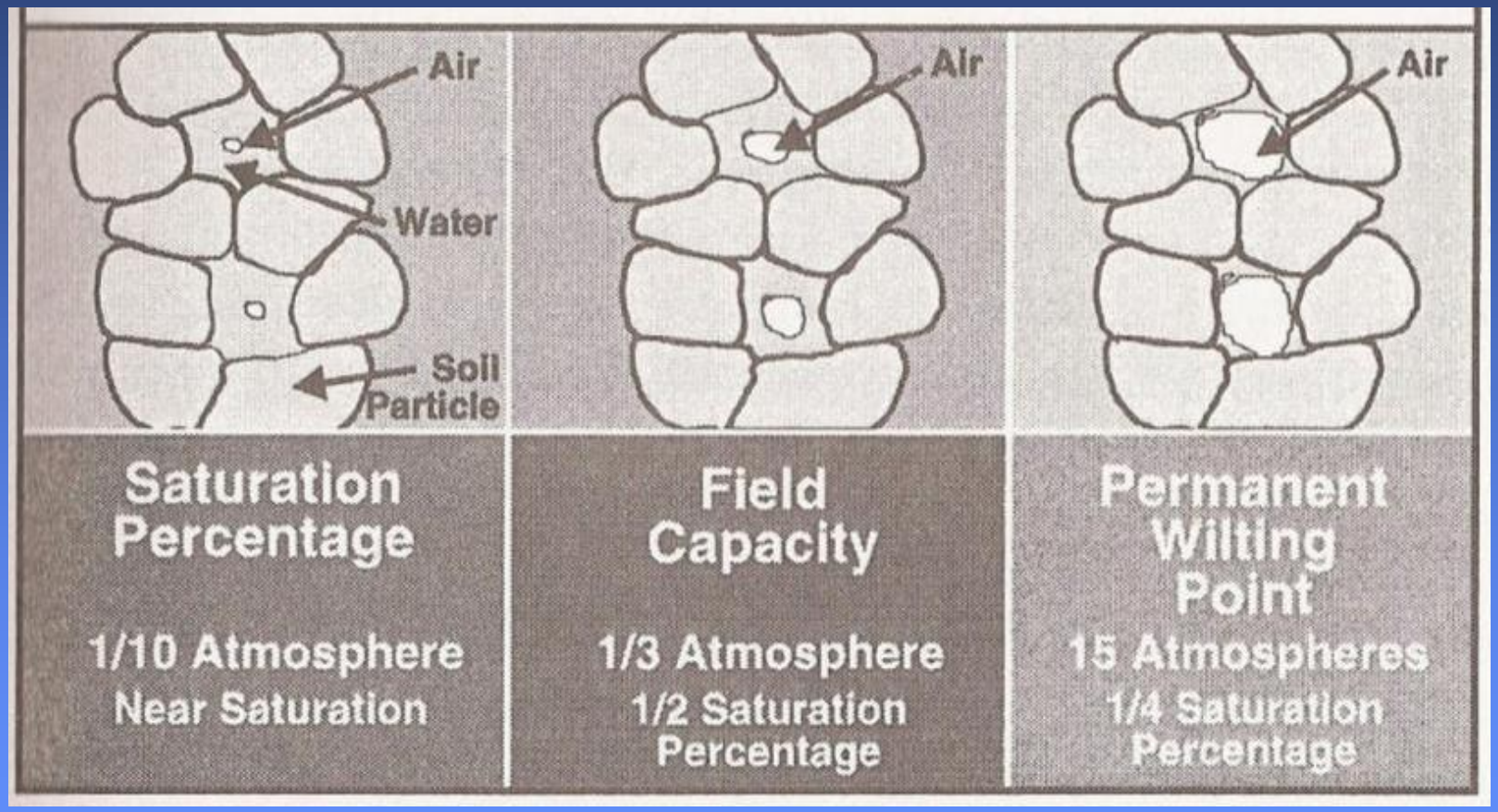
Permeability


SANDY LOAM
CLAY LOAM
15 min.
40 min.
1 hour
24 hours
4 hours
24 hours
48 hours
0
12
24
36
48
60
72
Depth - Inches from Bottom of Furrow
18 12 6 0 6 12 18
30 24 18 12 6 0 6 12 18 24 30
Distance - Inches from Center of Furrow

Clay Loam Soil in Davis

Soil Moisture Content

Terminology



Soil Structure

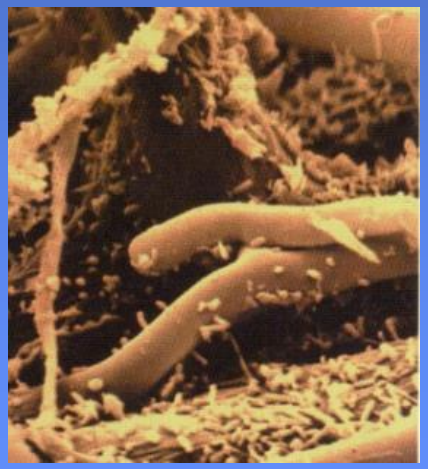
Structure - the arrangement of soil particles into aggregates

Good structure: holds water but has plenty of air space

Except for sands, soil particles don't exist as single particles but as aggregates

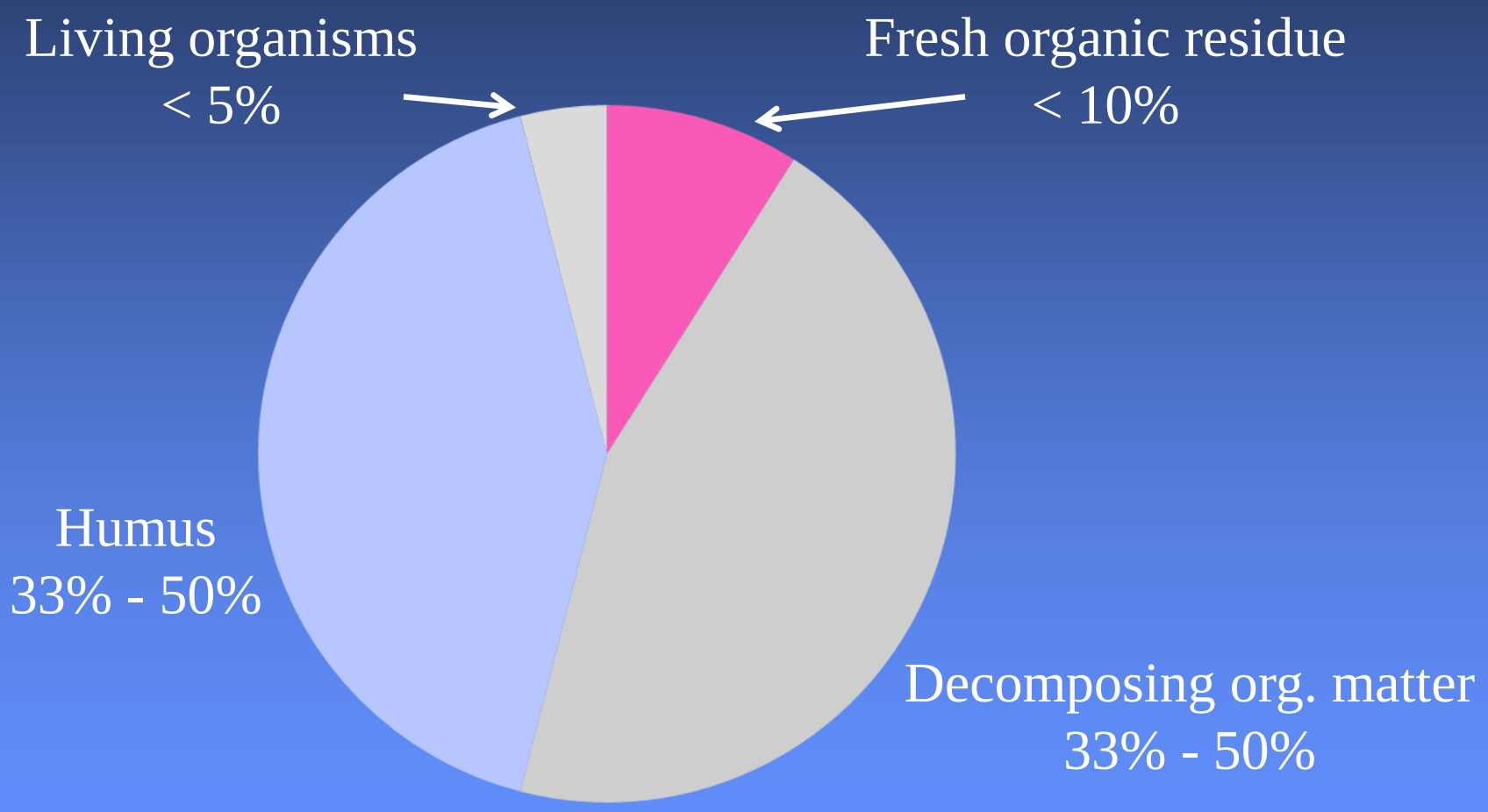
Soil Aggregation

Humus, plant & microbial exudates, and earthworm & soil insect feces act as “binding” agents



Soil Organic Matter and the Soil Food Web

Components of Soil Organic Matter



Soil Organic Matter

- Serves as energy source (food) for microorganisms, which promote stable aggregation of the soil particles
- Essential nutrients are obtained by plants as organic matter decomposes
- Enhanced by OM additions but destroyed by cultivation

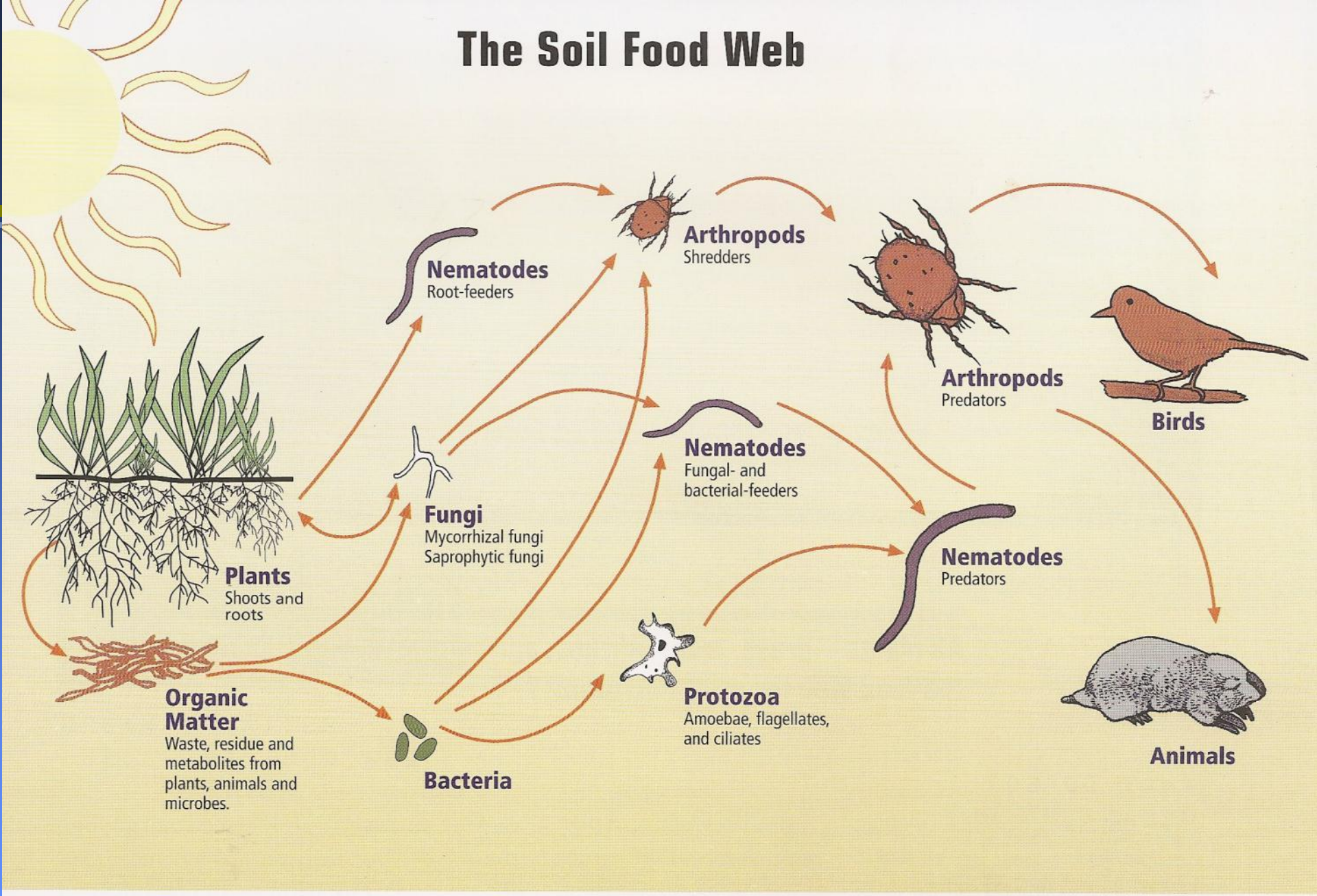
Humus

- What's left over after organic matter decomposes
- Cannot be seen by naked eye
- Very reactive (CEC), similar to clay
- In equilibrium with organic matter additions

Organic Matter Content

	% Organic Matter 0 to 6 inches
Venice peaty muck	60
Sacramento silty clay	5
CA Farm Academy	3.3
Yolo loam	1
Hanford sandy loam	0.5
Most Sacramento soils	0.75-1.5

The Soil Food Web

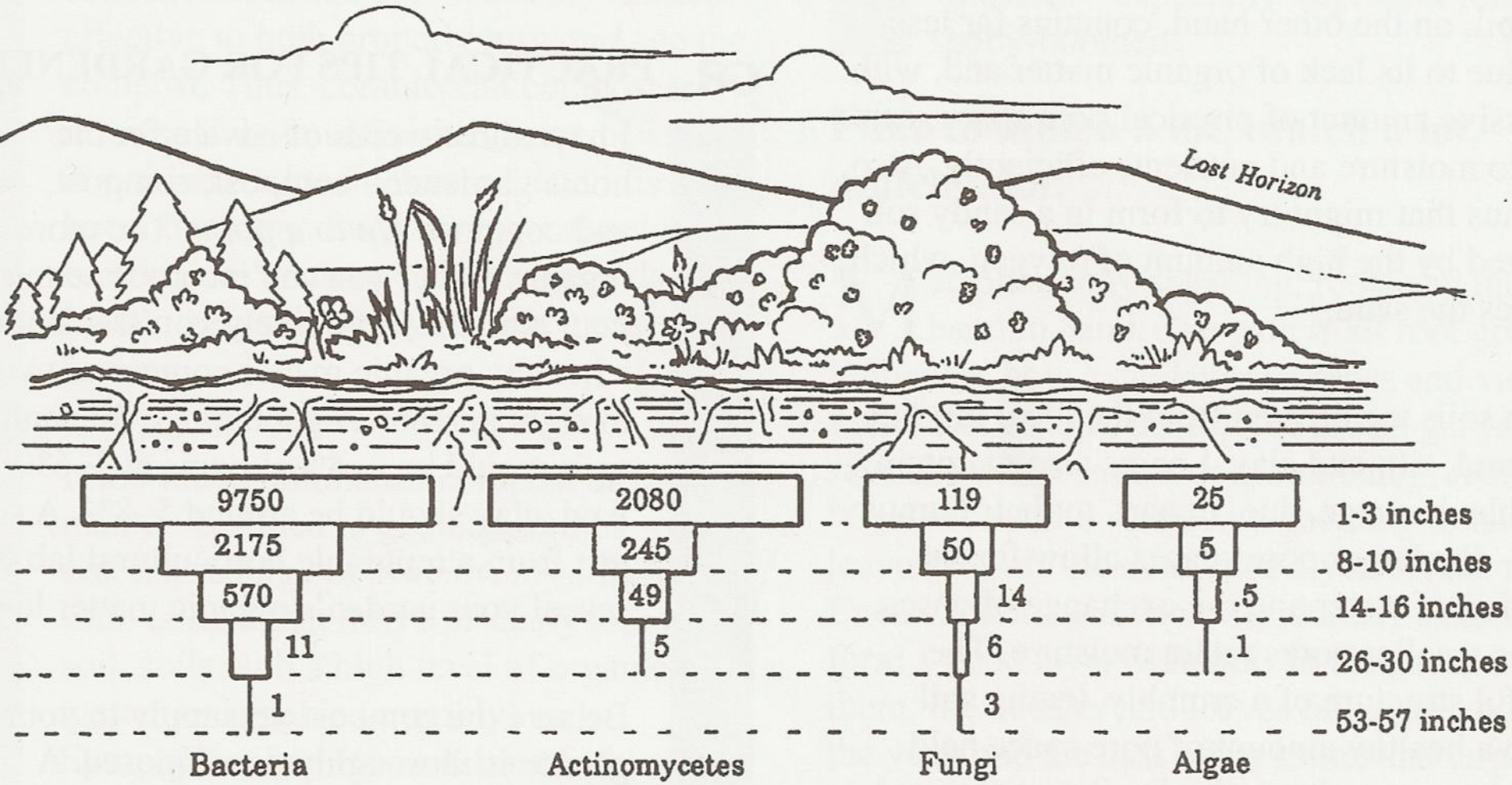


First trophic level:	Second trophic level:	Third trophic level:	Fourth trophic level:	Fifth and higher trophic levels:
Photosynthesizers	Decomposers Mutualists Pathogens, Parasites Root-feeders	Shredders Predators Grazers	Higher level predators	Higher level predators

Organism Populations in a Teaspoon of Various Soils

	Garden	Prairie	Forest
MICROBIAL (Teaspoon)			
Bacteria	100M to 1B	100M to 1B	100M to 1B
Fungi	Several yds.	10s to 100s yds.	1 to 40 mi. (conifers)
Protozoa	1000s	1000s	100,000s
LARGER ORGANISMS (Cubic foot)			
Arthropods	<100	500-2000	10K-25K
Earthworms	5-30	10-50	10-50

SOIL BIOTA POPULATIONS AS A FUNCTION OF SOIL DEPTH

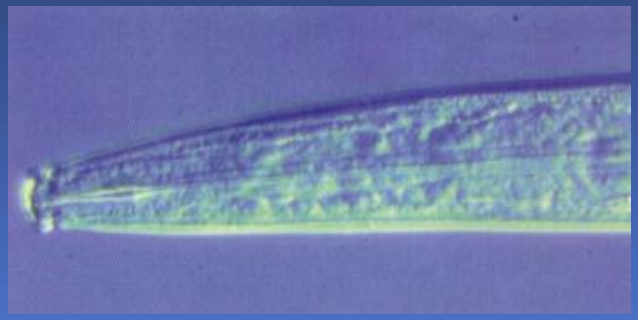


Source: Roots Demystified

Nematodes

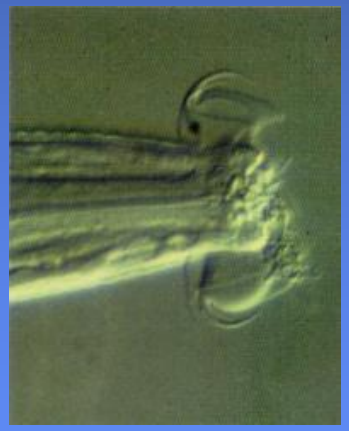
Some are pests, some beneficial

Nematode predator

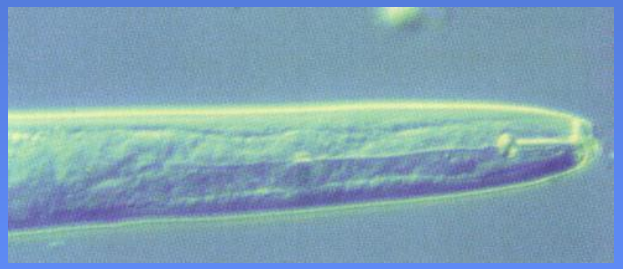


Fungal-feeding nematode

Root-feeding nematode

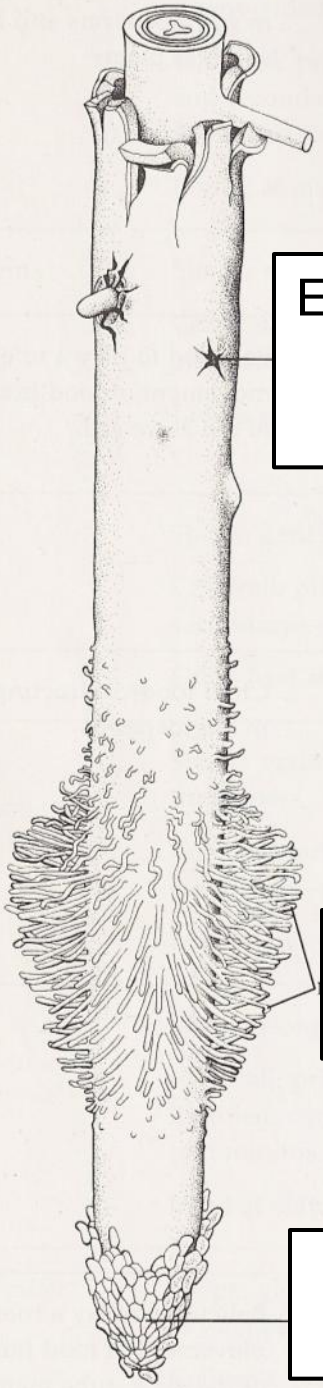


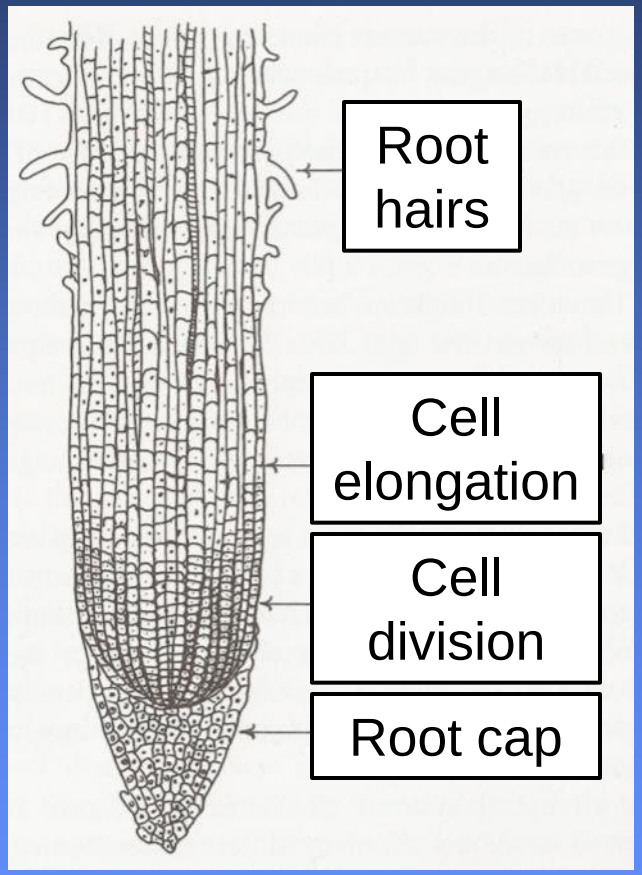
Bacterial-feeding nematode

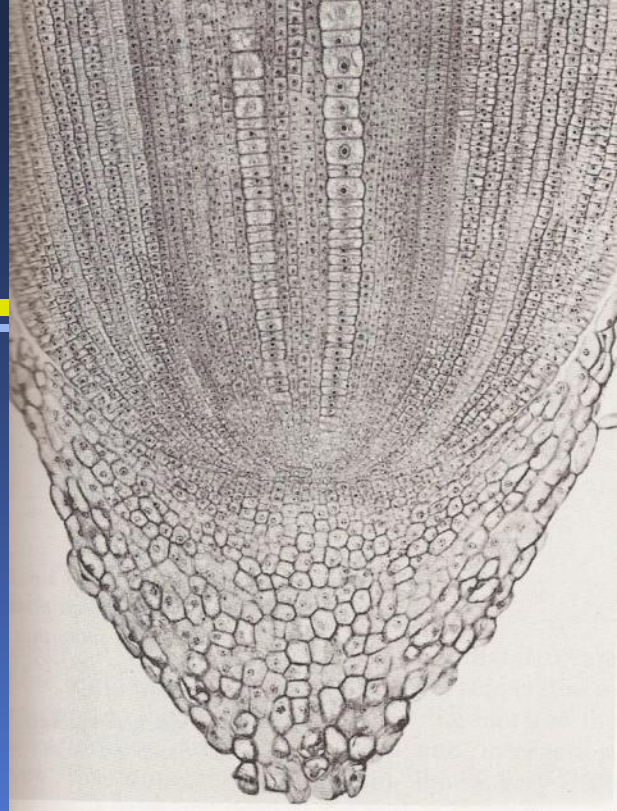


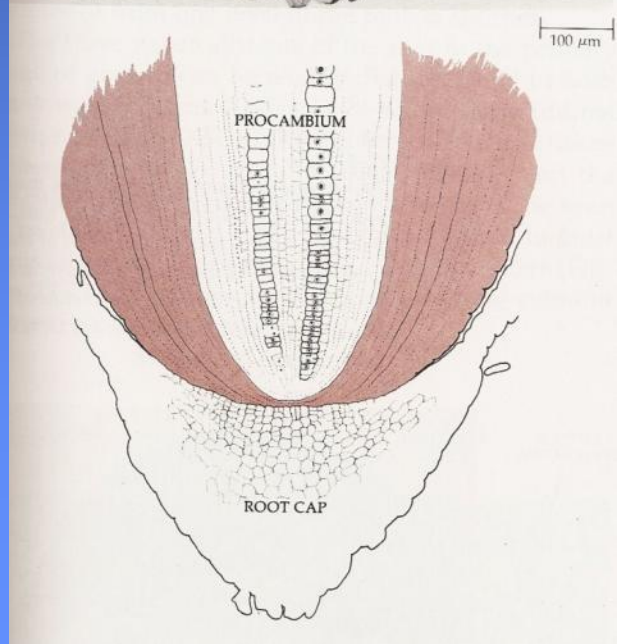
Lesion nematode

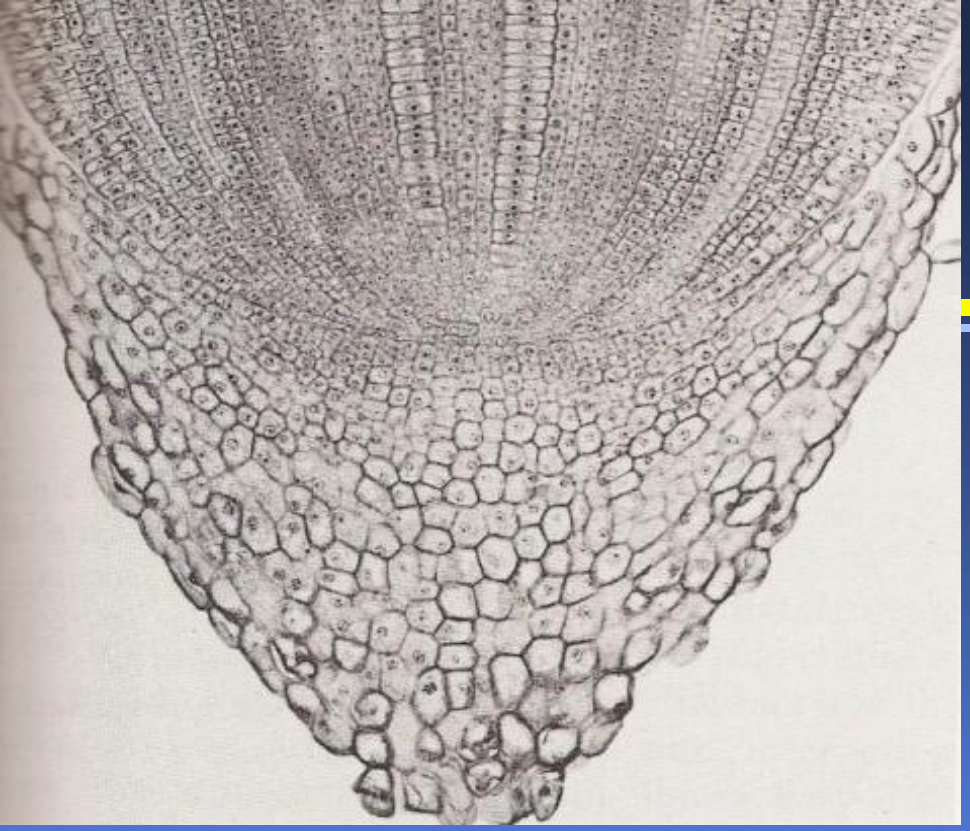
Anatomy of Young Roots

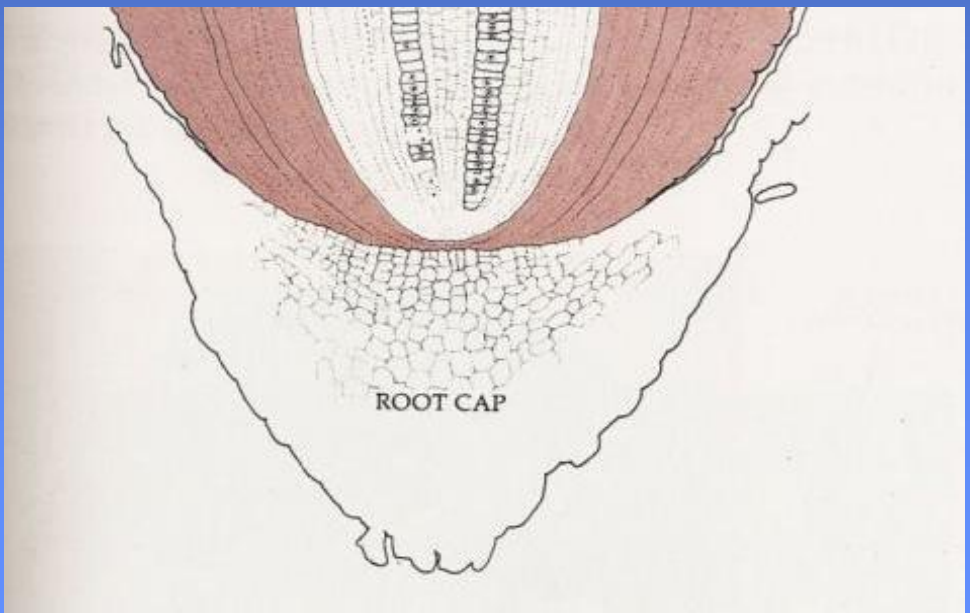










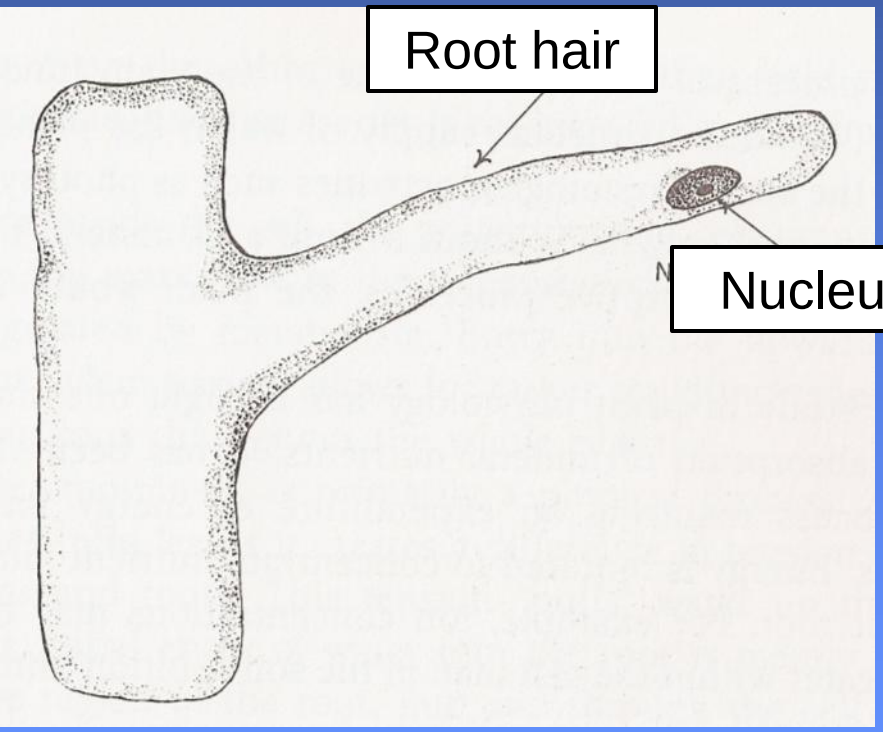


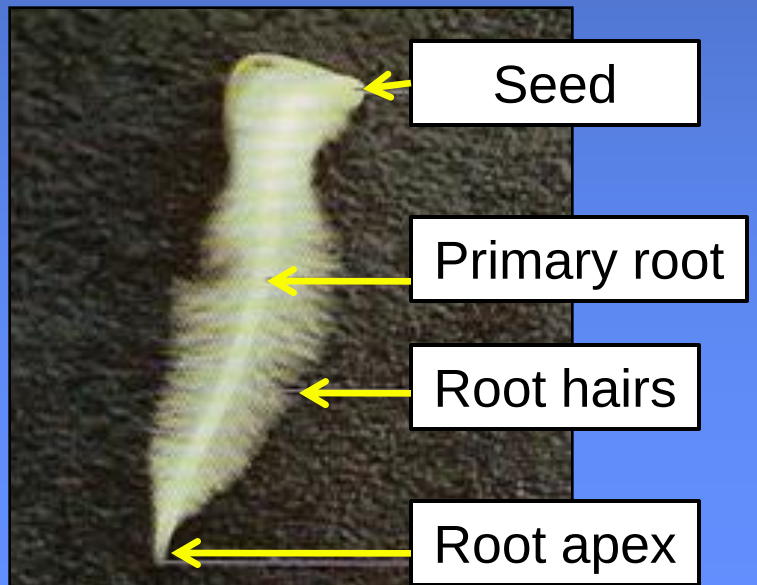
Root Cap

- Covers apical meristem
- Grouping of cells held within slimy “mucigel”
- Protects & lubricates root tip as it grows
- Cells slough off

Root Hairs

- Cells, not roots!
- Greatly increase root surface area
- Very short lived



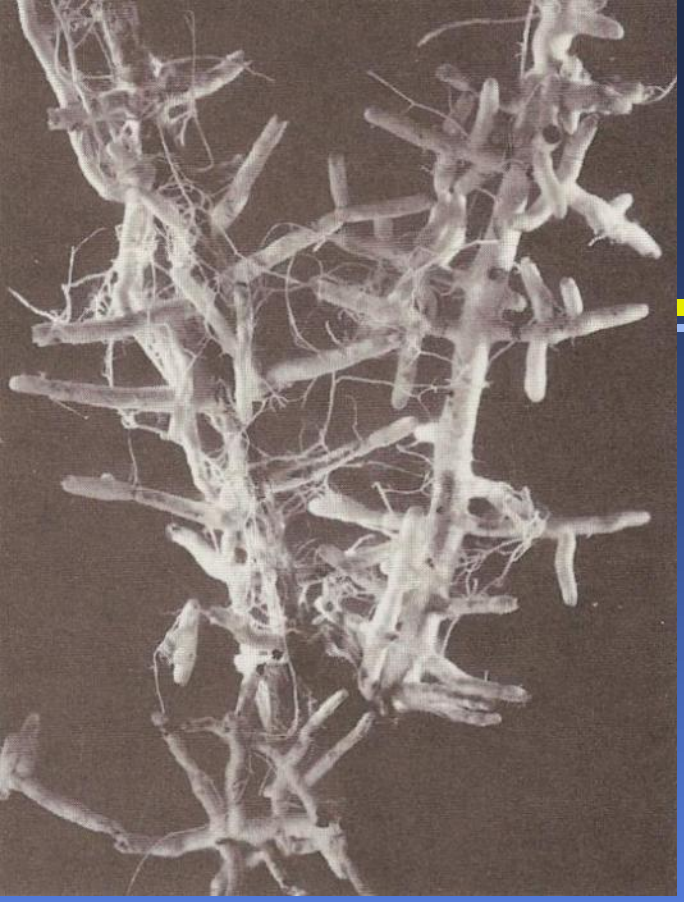


The Rhizosphere

- Region of soil that is directly influenced by root secretions (exudates) and soil microbes
- Exudates include amino acids, sugars, & acids
- Functions of exudates:
  - Protect against pathogens
  - Obtain nutrients
  - Stabilize soil aggregates

Mycorrhizae
("Fungus-Roots")

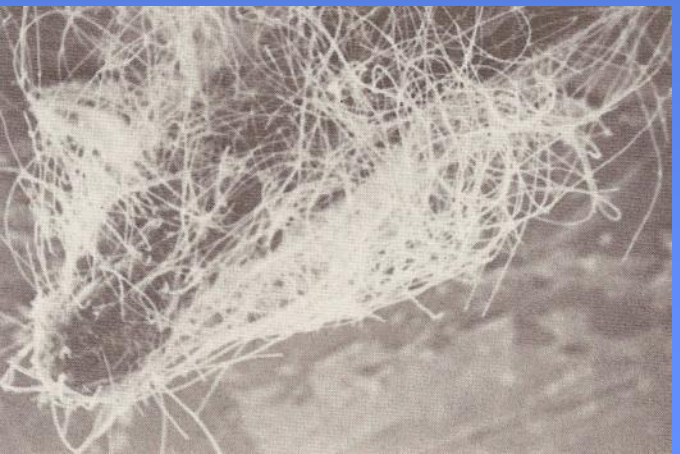
- Fungal infection of roots – symbiotic relationship
- Fungi – receive sugars; plants – nutrients & water
  - Mainly P, but also NH_4^+, NO_3^-, and K^+
- Poor growth without myc. where nutrients limited
- Lacking only in sedges & brassicas (cabbage fam.)
- Soil inoculation helpful only in poor/disturbed soils
- Two main types: Ecto- and endo-mycorrhizae

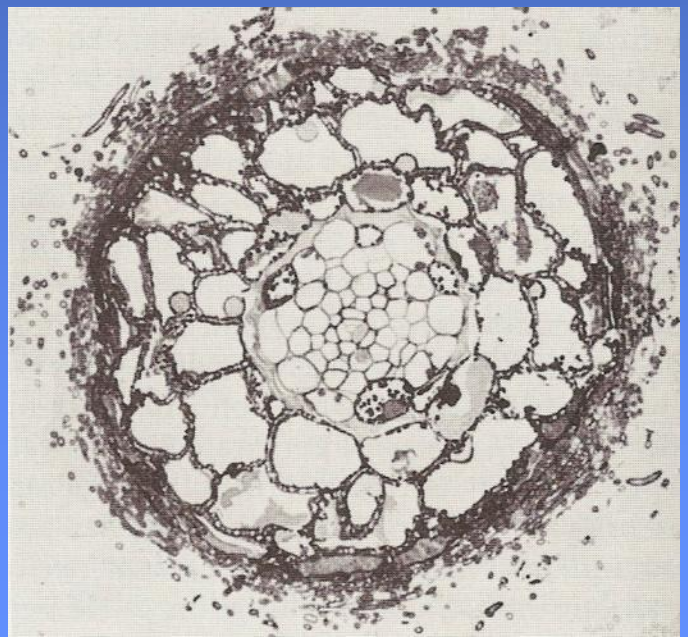


Mycorrhizal Fungi

Ecto-Mycorrhizae

- Grow on trees in pine, oak, beech, birch, and willow families
- Grow outside and between cells of young roots

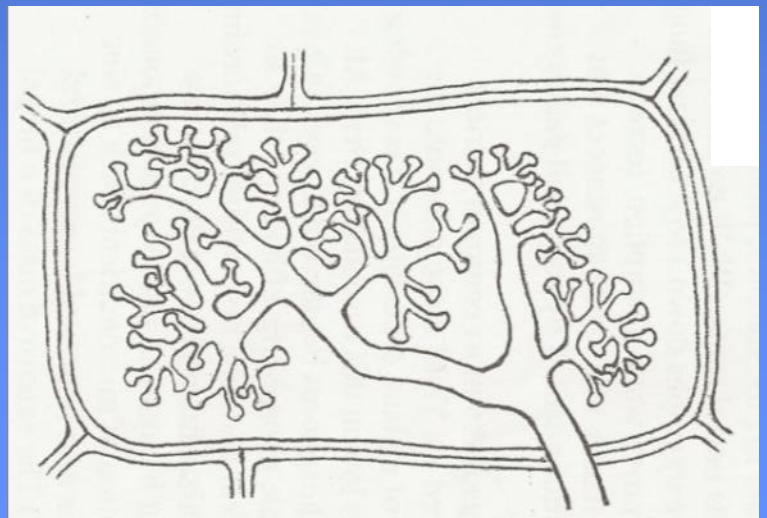




Mycorrhizal Fungi
Endo-Mycorrhizae

- Most important is vesicular-arbuscular myc. (VAM)
- 80% of plant species
- Most crops (monocots & dicots), hardwoods, non-pine conifers

- Infection directly into root cells



Mycorrhizae

Poor growth of forest trees without mycorrhizae where nutrients limited

Soil Fertility and Plant Nutrition

Essential Plant Nutrients

Major Nutrients from Air & Water	Major Nutrients from Soil	Minor Nutrients from Soil
➢Carbon	➢**Nitrogen**	➢Iron
➢Hydrogen	➢**Phosphorus**	➢Zinc
➢Oxygen	➢**Potassium**	➢Manganese
	➢Calcium	➢Copper
	➢Magnesium	➢Chlorine
	➢Sulfur	➢Boron
		➢Molybdenum

A & L WESTERN AGRICULTURAL LABORATORIES

1311 WOODLAND AVE #1 • MODESTO, CALIFORNIA 95351 • (209) 529-4080 • FAX (209) 529-4736

REPORT NUMBER: 13-035-064 **CLIENT NO:** 99999

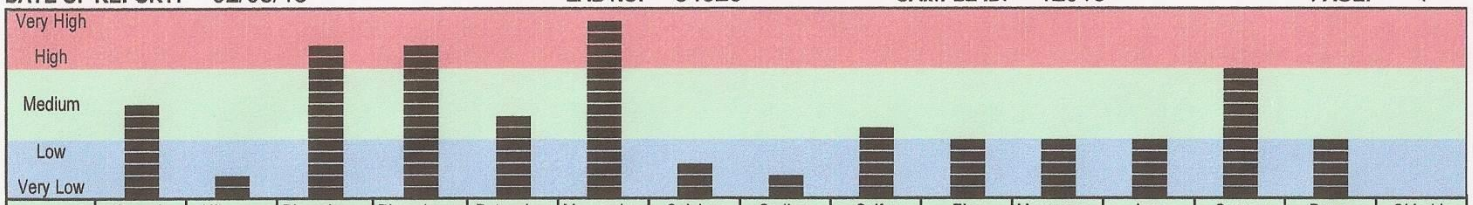
SEND TO: CALIFORNIA FARM ACADEMY
5265 PUTAH CREEK RD
WINTERS, CA 95694-

GROWER: CENTER FOR LAND-BASED LEARNING

SUBMITTED BY: MAUREEN THOMPSON

Graphical Soil Analysis Report

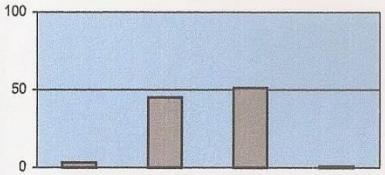
DATE OF REPORT: 02/08/13 **LAB NO:** 54329 **SAMPLE ID:** 12013 **PAGE:** 1



Analyte	Organic Matter %	Nitrogen NO_3-N ppm	Phosphorus Weak Bray ppm	Phosphorus $NaHCO_3$-P ppm	Potassium K ppm	Magnesium Mg ppm	Calcium Ca ppm	Sodium Na ppm	Sulfur SO_4-S ppm	Zinc Zn ppm	Manganese Mn ppm	Iron Fe ppm	Copper Cu ppm	Boron B ppm	Chloride Cl ppm
Results	3.3	4	43	39	268	1187	2205	29	15	1.0	3	11	1.8	0.5	

LOW AVERAGE HIGH

Percent Cation Saturation (computed)



Potassium K %	Magnesium Mg %	Calcium Ca %	Sodium Na %
3.2	45.2	51.0	0.6

ACIDIC BASIC

ECe dS/m	CEC meq/100g	Ex. Lime	pH
0.5	21.6	L	7.1

INCREASING SALINITY →

← INCREASING NEED FOR LIME

Buffer pH:

Soil Fertility Guidelines

CROP: VEGETABLES **RATE:** lb/acre **NOTES:**

Dolomite (70 score)	Lime (70 score)	Gypsum	Elemental Sulfur	Nitrogen N	Phosphate P_2O_5	Potash K_2O	Magnesium Mg	Sulfur SO_4-S	Zinc Zn	Manganese Mn	Iron Fe	Copper Cu	Boron B	
		3000		130	40	20			5					

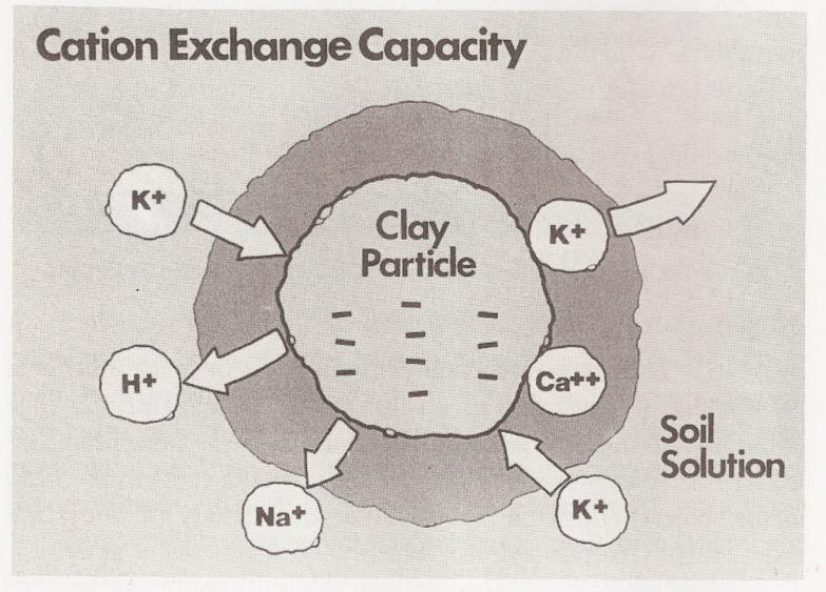
COMMENTS

NITROGEN: Use local conditions and experience with variety to determine rates and timing. Allow for nitrate levels in your water source also (ppm NO3 X 0.61 = lb N/ac-ft water). Monitor plant-N.
MIXED VEGETABLES: Band up to 20 lb N + 40 lb P2O5 + 20 lb K2O + 5 lb S/ac 3 inches below and to the side of seeds/transplants. Side-dress 2/3 of remaining N at thinning time, then as necessary.
MAGNESIUM: If levels are very high (generally, they increase with depth), one may encounter drainage problems and potassium uptake may be hindered. Extra calcium may provide some benefit.
CALCIUM: As a guideline, (CEC x 200 x 0.65) - ppm Ca on soil report = lb Ca required per 3 acre-inch soil depth to raise to 65% Ca. Gypsum contains about 400 lb/ton, and lime possibly 600 lb/ton.

Mike Buttress, CPAg
A & L WESTERN LABORATORIES, INC

Cation Exchange Capacity (CEC)

- A measure of soil fertility
- Cations in soil solution in dynamic equilibrium with clay & humus particles
- Varies by soil type and % organic matter



Typical CECs Based on Soil Texture

Soil Texture	Typical CEC Range
	meq/100g
Sand	2 – 6
Sandy Loam	3 – 8
Loam	7 – 15
Silt Loam	10 – 18
Clay & Clay Loam	15 – 30

High vs. Low CEC

CEC 11-50

- High clay or OM content
- Greater capacity to hold nutrients
- More lime or sulfur needed to adjust pH
- High water-holding capacity

CEC 1-10

- High sand content
- N & K leaching more likely
- Less lime or sulfur needed to adjust pH
- Low water-holding capacity

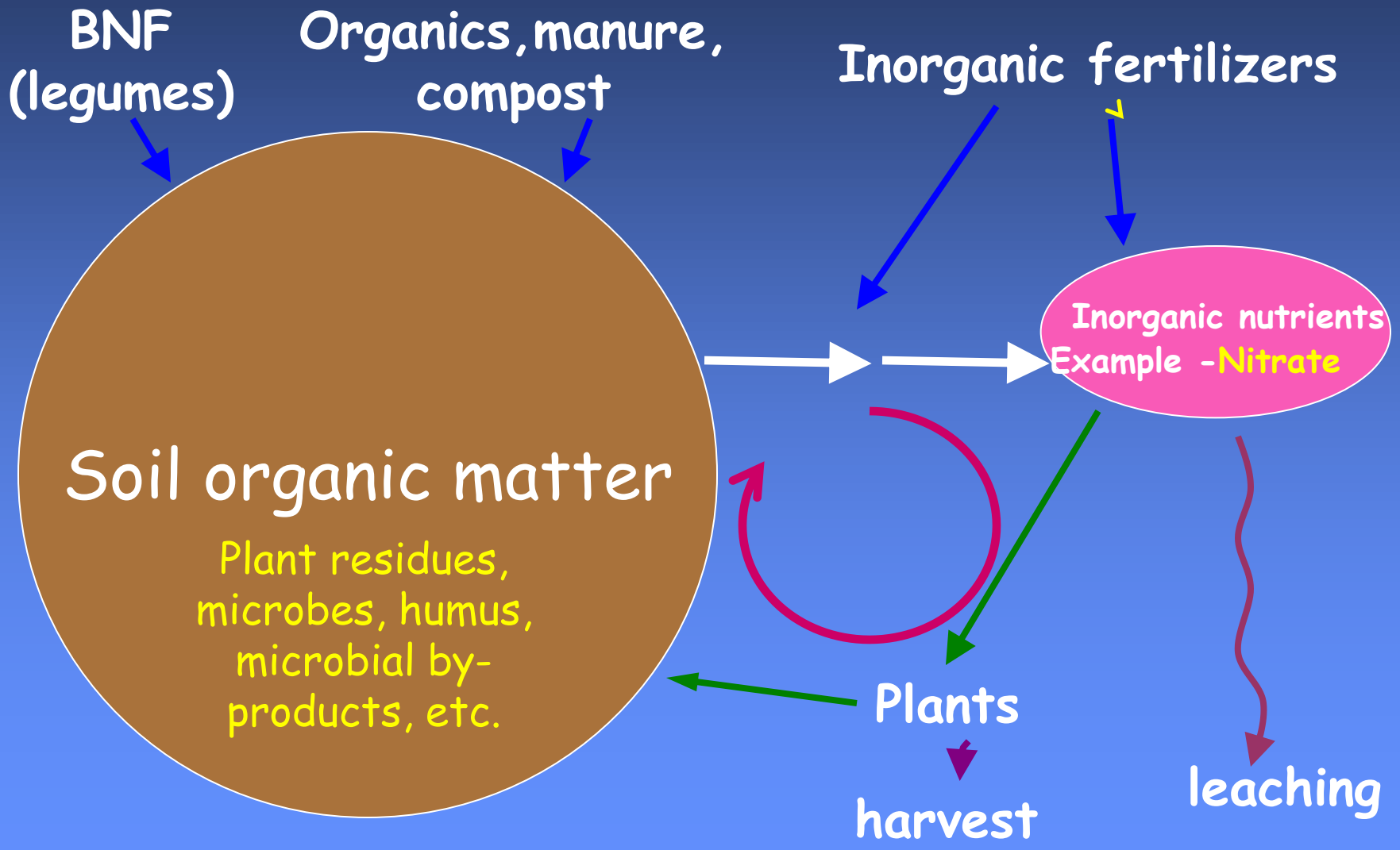
Mobility of Nutrients

	Ionic Form	Soil Mobility	Plant Mobility
N	NH_4^+	Immobile	Immobile
N	NO_3^-	Mobile	Mobile
P	$H_2PHO_4^-$	Immobile	Immobile
K	K^+	Immobile	Mobile
Ca	Ca^{++}	Immobile	Immobile
Mg	Mg^{++}	Immobile	Mobile
Zn	Zn^{++}	Immobile	Immobile
Mn	Mn^{++}	Immobile	Immobile

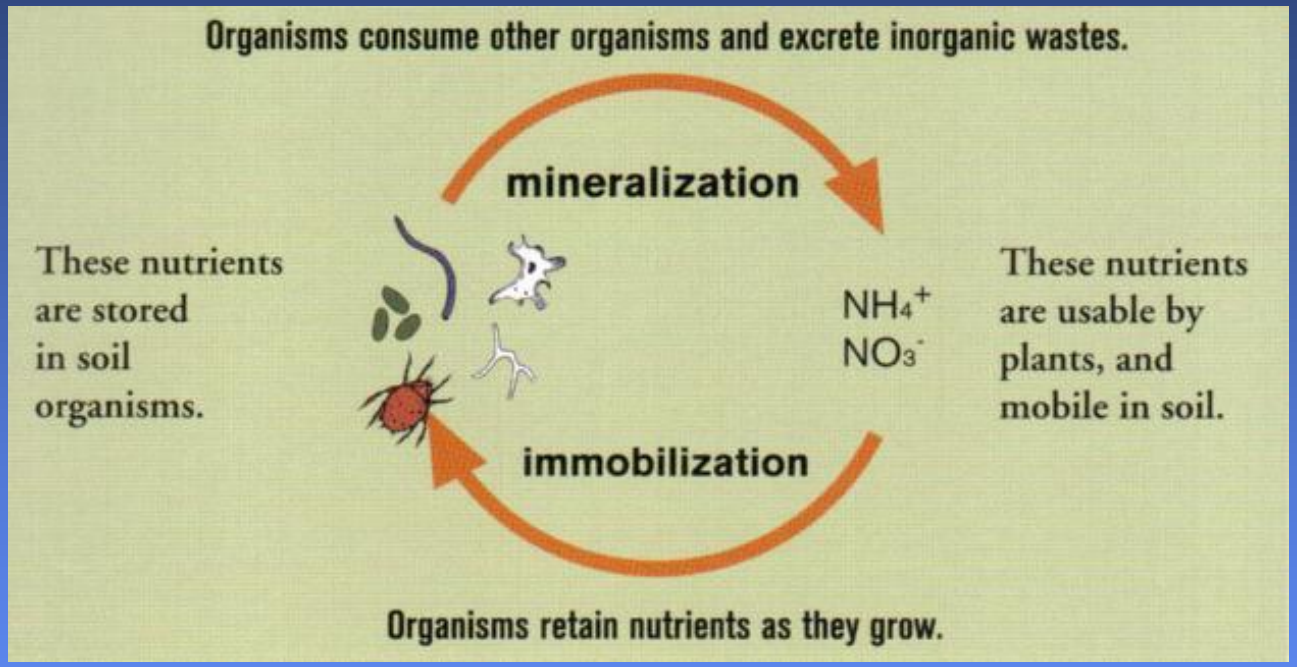
Roles of Nitrogen (N)

- Converts to amino acids in plant
  - » Building blocks for proteins
  - » Essential for cell division & plant growth
- Necessary for enzyme reactions
- Constituent of chlorophyll (photosynthesis)
- Promotes vigorous vegetative growth

"Simplified" Nitrogen Cycle



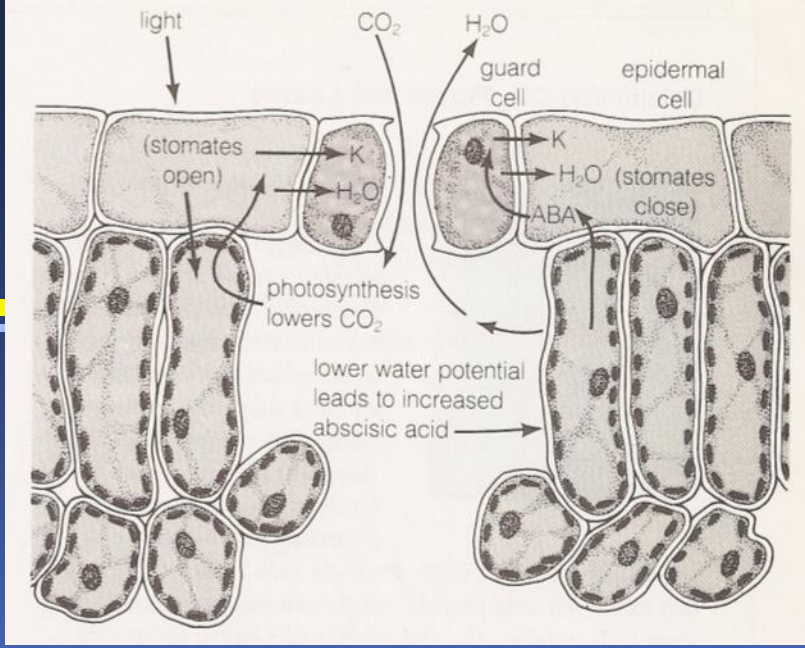
Mineralization and Immobilization



Roles of Phosphorus (P)

- Plays role in photosynthesis, respiration, energy storage & transfer, cell division & enlargement
- Promotes flower and fruit development
- Promotes seedling root growth
- Contributes to disease resistance

Roles of Potassium (K)



- Essential for photosynthesis
- Used as an enzyme to make proteins & sugars
- Important in membrane permeability
- Opening & closing of stomates
- Helps plant use water more efficiently by promoting turgidity
- Increases disease resistance

Potash Banding

- K attaches to soil particles
- K concentrated, so extra K leaches down

- Broadcasting K (or P) on ground has little effect – nutrients are locked up in top 1-2” of soil
  - Must be banded or incorporated

Manures
Characteristics and Uses

- Poultry, dairy, feedlot, steer, rabbit, sheep/goat
- May contain salts that harm plant growth, and weed seeds
- Poultry may have >3%N (ammonia smell)
- Aged feedlot manure may have <1% N

Manures
Typical Nutrient Content

	% Dry Weight Basis		
Manure	N	P	K
Chicken, fresh	5.1	2.0	1.8
Chicken, partially composted	2.9	3.3	3.3
Steer	2.5	0.4	0.7
Horse	1.8	0.5	1.2

Compost
Characteristics and Uses

- Contains diverse microbial populations
- Contains most nutrients required by plants
- May contain weeds & plant pathogens
- N content usually about 1-1.5%, very slow release
- Usually considered a soil amendment, not fertilizer

Available N from Manures, Compost

Decay Series

- UC research, 1970s
- Average plant-available N over 3 years (years 1, 2, and 3):
  - Chicken (90%, 10%, 5%)
  - Dairy (75%, 15%, 10%)
  - Feedlot (35%, 15%, 10%)
  - Compost (~10% in year 1)

Chemical vs. Organic Fertilization

- Plants take up nutrients from organic and chemical sources (no preference)
- Organic fertilizers feed soil microbes and require them for breakdown ("Feed the soil")
- Microbes (and roots) release compounds like organic acids, enzymes, and chelates → convert nutrients from organic form into a plant-available (soluble) form

Advantages of Chemical Fertilizers

- Nutrients available to plants immediately
- Produce exact ratio of nutrients desired
- Ratios and chemical sources easy to understand
- Inexpensive

Disadvantages of Chemical Fertilizers

- Made from nonrenewable sources (fossil fuels)
- May not promote soil health
  - No decaying matter for improving soil structure
  - Most do not replace micronutrients
- Nutrients readily available → chance of overfert.
- Tend to leach faster than organic
- Long-term use can change soil pH, harm soil microbes, increase pests

Advantages of Organic Fertilizers

- May also improve soil structure
- Most are slow-release; not easy to overfertilize
- Renewable and biodegradable
- Can make your own from waste (compost, worm castings) or obtain locally (manure)

Disadvantages of Organic Fertilizers

- May not release nutrients as they are needed
- Nutrient content of manure & compost often unknown
- % nutrients usually lower than chemical fertilizers
- Tend to be bulkier, requiring more fossil fuels; more expensive

Soil pH

pH Scale
0-14

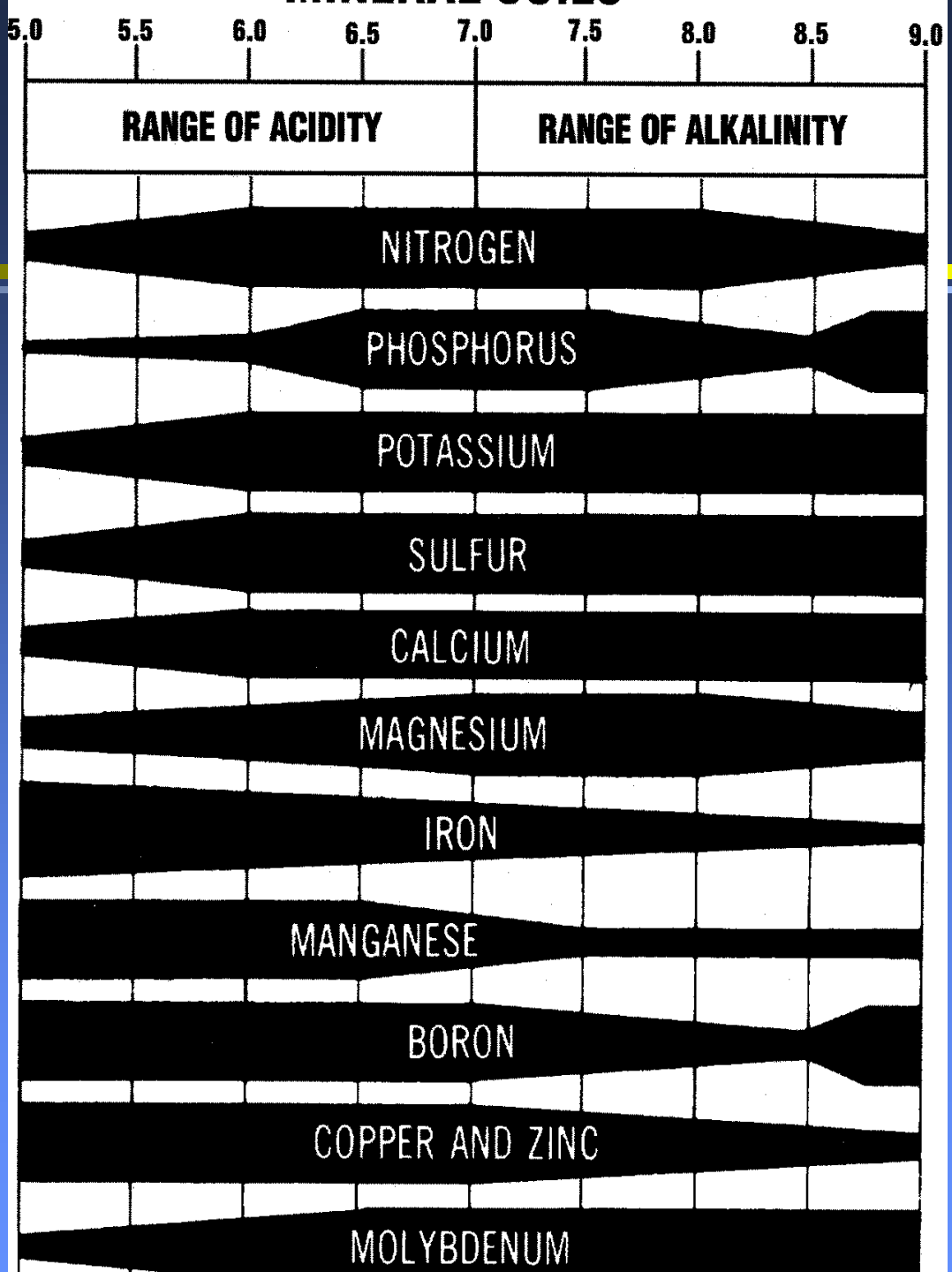
1 Battery acid
2 Lemon juice
3 Vinegar
4 Tomatoes
5 Beer
6 Milk
7 Pure water
8 Sea water
9 Baking soda
10 Milk of magnesia
11 Ammonia
12 Lime
13 Lye
14

Soil pH

Acidic	Neutral	Alkaline
Low pH		High pH
(4.5 to 5.5)		(7.0 to 8.0)

pH 6.5 to 7.0 = generally “ideal”, maximum availability of primary nutrients (N, P, & K)

pH and Nutrient Availability



← Iron

← Manganese

High pH Leads to Micronutrient Deficiency

Materials for Changing pH

Raising pH	Lowering pH
Limestone	Soil sulfur
Hydrated lime	Ammonium-based fertilizers
Oyster shell lime	
Dolomite	
Wood ash	

Gypsum does not change soil pH

Nutrient Analysis

Soil Sampling

- Doesn’t always tell what plants take up
- Good for baseline info and detecting deficiencies
- Sample in rooting zone from different areas
- Include at least 1 pint per sample in a quart plastic zip-lock bag, take to lab
- Include: Total N, NO3-, P, K, Ca, Mg, soil texture, pH, OM, CEC, salts(?)

Nutrient Analysis

Plant Tissue Sampling

- Tells what plant actually took up
- Standards only available for crop plants
- Best timing
  - » Annual crops – during active growth
  - » Tree crops – July
  - » Grapes – at bloom (petioles)
- Include 30+ leaves/sample → into small paper bag, refrigerate, take to lab ASAP
- Include: N, P, K, Fe, Mn, Zn, salts(?)

Dealing with Soil Compaction and Restrictive Soil Layers

Some soil layers restrict air, water, and root penetration

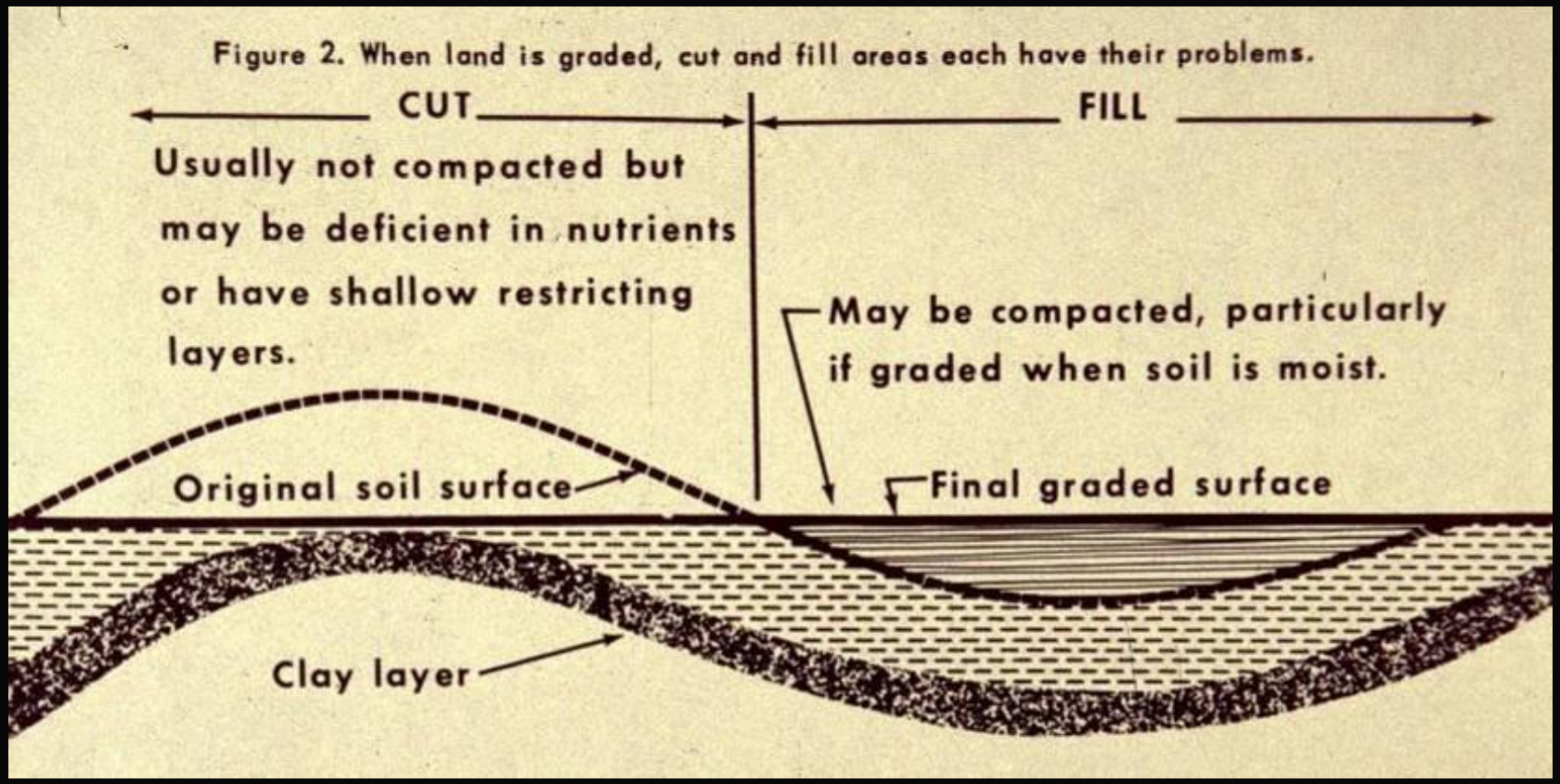
- Hardpan – cemented (by silica, iron, carbonates)
- Claypan – higher clay than overlying layer
- Crust – brittle, compact/hard when dry
- Traffic or compaction pan – caused by vehicles, tillage implements, feet, hooves

Cemented Hardpan

Cemented Hardpan

- Primary cementing agent
  - » In our area – silica
  - » In Southwest: (caliche) – carbonates
- Sand, silt, & clay grains are cemented together into a hard, impermeable layer of varying thickness
- Often not continuous or uniform across the landscape

Effects of Grading



Fair Oaks
Horticulture Center,
1997

Soil Compaction

Effects of Compaction on Soil

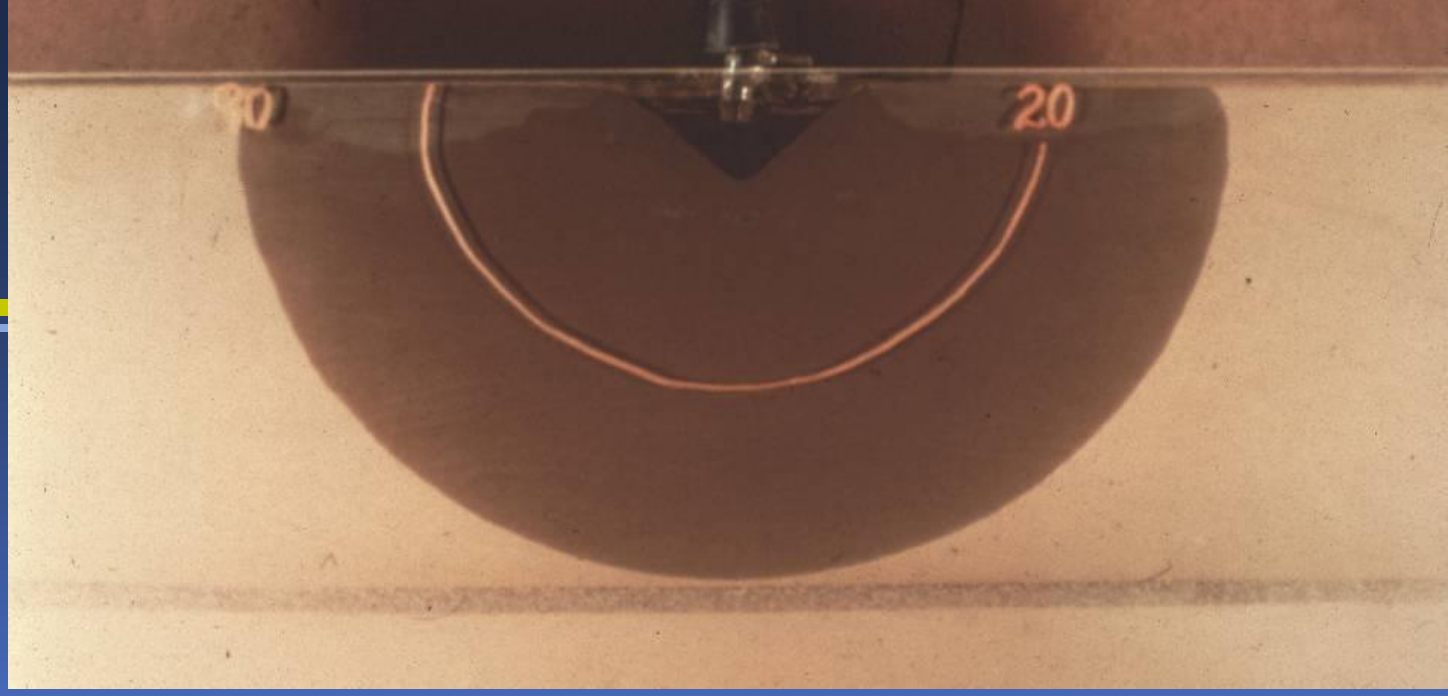
- Soil structure is destroyed – pore space is severely reduced
- Soil drains slowly and is prone to being anaerobic
- Compacted soil physically impedes root growth

Soil Stratification

Stratified Layer

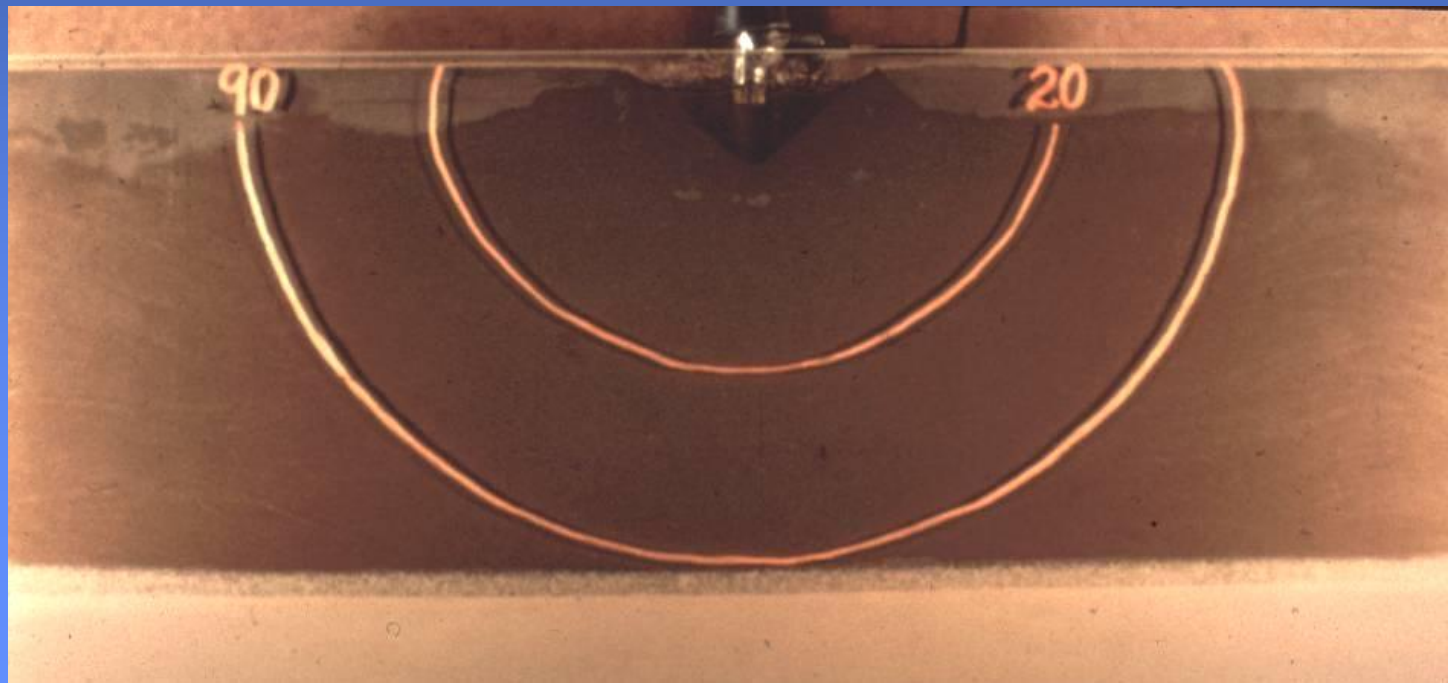
Loam →

Sand →



Loam →

Sand →



Dealing with Compacted and Layered Soils

The Main Goal

Create & maintain soil conditions most favorable for root growth and water movement

Deep Ripper

Mix the Soil

Plow

Backhoe

Clay Soils

Dealing with Clay Soils

- Cultivation helps, but clay particles resettle
- Avoid compacting, especially when wet
  - » Equipment, foot traffic, etc.
- Provide drainage
- Add organic matter (cover crops, compost)

Can Gypsum Improve Your Soil?

Yes

If soil is impermeable due to excess Na,
Or due to low Ca:Mg ratio

Probably Not

If soil is impermeable due to fine texture,
compaction, or hardpan

Definitely Not

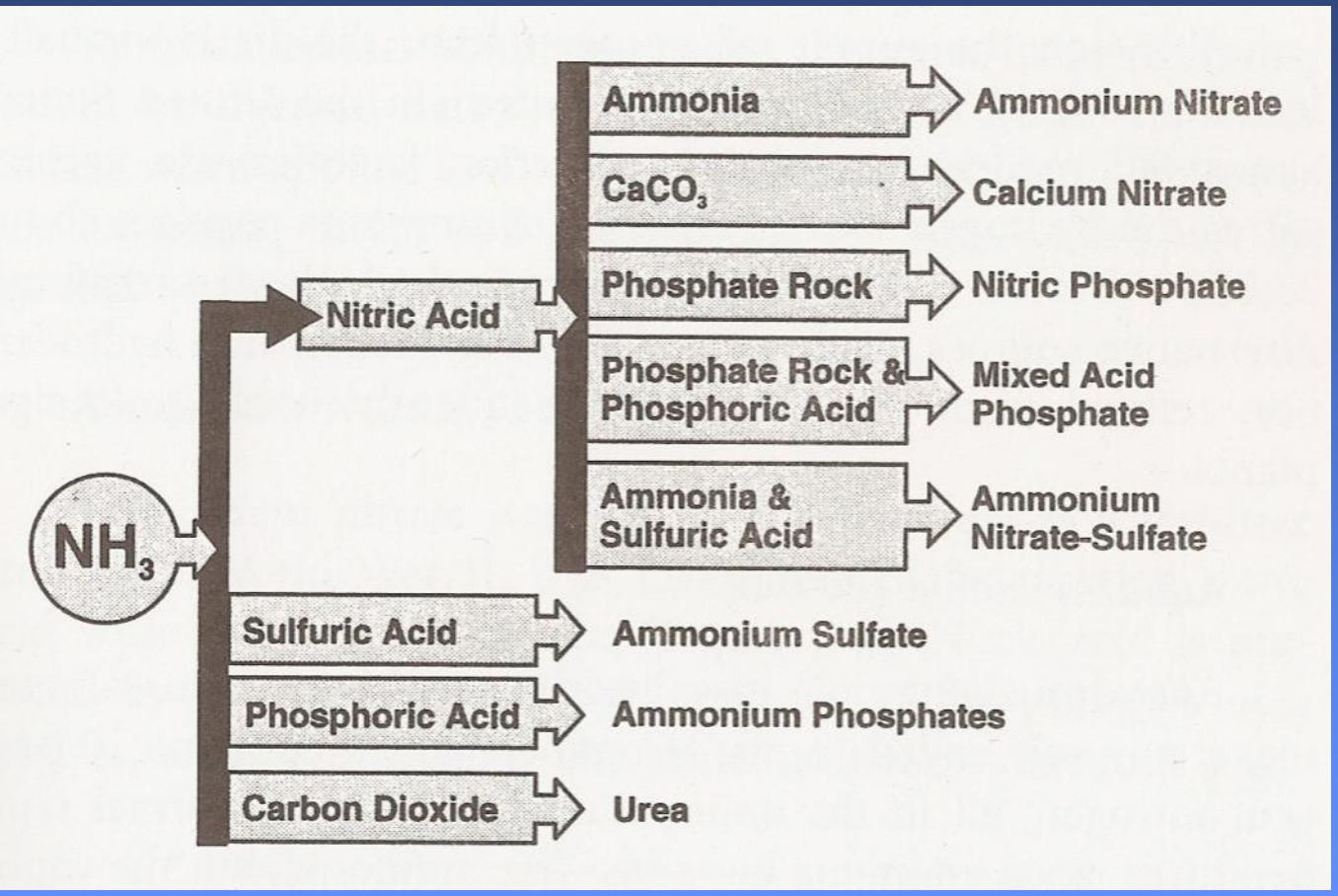
If soil is permeable and water penetrates well

Questions?

Making of Chemical Nitrogen Fertilizers

- Natural gas = 98% methane (CH_4)
- Chemical reactions → hydrogen gas (H_2)
- Makes ammonia, energy intensive
- Compressed into liquid = Anhydrous ammonia

Conversions of Ammonia to Various N Fertilizers



Examples of Chemical Nitrogen Fertilizers

- Ammonium sulfate (21-0-0-24S)
- Ammonium nitrate (34-0-0)
- Urea (46-0-0)
  - Highest %N; protein substitute in feeds

Slow-Release N Fertilizers

- Synthetic
  - UF, MU, IBDU (uncoated; short & long-chain polymers)
  - Polymer-coated (e.g., Osmocote)
- Natural (e.g., compost, feather meal)
- Longer lasting, not readily leached
- Label says “Slow Release Nitrogen”
  - Water Insoluble Nitrogen (W.I.N.)

Fertilizer Analysis

N	-	P	-	K	-	S
21	-	0	-	0	-	24

Ammonium Sulfate

Calculating Fertilizer Amounts

<u>Divide the amount of N needed by the %N</u>

- Ammon. sulfate (21-0-0)

  1 lb. N/1,000 sq. ft. ÷ 0.21 = 4.8 lbs.

- Multi-purpose (16-16-16)

  0.5 lb. N/tree ÷ 0.16 = 3.1 lbs.

- Fruit tree fert. (12-4-8)

  0.75 lb. N/1,000 sq. ft. ÷ 0.12 = 6.3 lbs.

  6.3 lbs. fert. x 0.04 = 0.25 lb. P_2O_5

  6.3 lbs. guano x 0.08 = 0.5 lb. K_2O

Fertilizer Blends

- “Balanced” fertilizer = Contains N, P, & K
- N-P-K numbers not always the same
- Examples: 16-16-16 (multi-purpose), 12-4-8 (fruit tree & vine), 5-10-10 (tomato & veg.), 4-8-5 (camellia/azalea), 25-6-4 (lawns)
  - (Blends are not standardized!)

Plant-Based Organic Fertilizers

- Alfalfa meal
- Cottonseed meal
- Soybean based
- Kelp/seaweed
- Humic acid and humate products

Alfalfa Meal
(About 2-1-2)

- From alfalfa plants, pressed into pellets
- Also contains micronutrients
- Especially good for roses, also vegetables
- Fairly quick N release

Cottonseed Meal
(About 6-2-1)

- Derived from the seed in cotton bolls
- Some people have concerns about heavy pesticide use on cotton and remaining in the seed oils, so they choose organic
- Very slow N release

Kelp/Seaweed

- Derived from sea plants off Norway, N. Calif.
- Available as liquid, powder, or pellet
- Applied to the soil or as a foliar spray
- Little N-P-K, mainly used for micronutrients, hormones, vitamins, and enzymes
- “Can help increase yields, reduce plant stress from drought, and increase frost tolerance”

Humic Acid and Humate Products

- Complex organic compounds
- Touted to enhance soil microbial life
  - Enables plants to extract nutrients from soil
  - Improves soil structure
  - Enhances root development
  - Helps plants withstand stresses
- May receive same benefits from adding compost

Mining of Rock Phosphate

- Source : Natural deposits in N. America, China, Morocco, & former Soviet Union
- N. America – Florida, Idaho/Mont./Utah/ Wyoming, N. Carolina, Tennessee

Rock Phosphate

- Hard-rock phosphate
  - 20% P and 48% Ca – can raise pH
  - Breaks down very slowly
- Soft-rock phosphate
  - 16% P and 19% Ca, many micronutrients
  - Form that plants can use more easily
  - Breaks down very slowly

Mining of Potassium Fertilizers

- World reserves deposited when water from ancient inland oceans evaporated
  - K salts crystallized into beds of potash ore
  - Covered by thousands of feet of soil
- Most deposits chloride (KCl), some sulfate (K_2SO_4)
- From Canada (#1), Russia, Belarus, US (#7)
  - New Mexico, Utah, Canada

Potash

- K compounds and K-bearing materials (esp. KCl)
- Historically – KCO_3 – Bleaching textiles, making glass, making soap (lye)
  - Made by leaching ashes and evaporating the solution in large iron pots, leaving a white residue called "pot ash“
  - Term later used for K fertilizer
- KCl = Muriate of potash
- KSO_4 = Sulfate of potash

Animal-Based Organic Fertilizers

- Animal killed
  - Blood meal
  - Bone meal
  - Feather meal
  - Fish products
- Animal not killed
  - Bat guano
  - Manure/compost

Blood Meal

13-1-0.6 (80% protein)

- Bovine blood collected from processing plants, agitated, dried, granulated
- Quick N release – ammonia can burn plants

Bone Meal

1-13-0 to 4-12-0, + 22% Ca

- Uses
  - Blooming bulbs (P)
  - May help prevent blossom-end rot (Ca)
  - Also useful for root growth of transplants (P)
- Bone meal is alkaline, so apply to soils of pH < 7
  - Need acidic soil to convert to plant-available P

Feather Meal

Usually 12-0-0

- Made from feathers of slaughtered poultry by hydrolyzing under high heat and pressure and then grinding
- Slow release of plant-available N

Fish Products

- Many forms, have some P, K, & micronutrients
- Fish emulsion, liquid fish (4-5% N)
  - Derived from fermented remains of fish
  - Has a fishy smell
- Hydrolyzed fish powder (11% N)
  - Mixed with water and sprayed on plants
- Fish meal (powder) (10% N)
  - Applied to soil

Bat/Seabird Guano

- Poop from bats and seabirds – Islands in Pacific & other oceans
  - From caves – loss of bats & biodiversity
- Bat guano: 3-10% N, up to 12% P, 1% K
- Seabird guano: Up to 12% N & P, 0-2% K
- More expensive than land-animal manures

Chemical (Inorganic) Fertilizers

- No C-H linkage, so not used as energy source by soil microbes
- Most are quick-release
- Because of the lack of carbon, fertilizers “feed the plant but not the soil.”

Timing of Fertilization and N Fate

Tree Crops

- Early spring application – much N moves to leaves, shoots
- Early summer – most N to branches, trunk, roots, buds; very little to fruit
- Apply N late spring/early summer to reach flower buds in early spring
- Mid to late summer – mainly to roots
  - » utilized for early spring growth & flowering
- Late fall through winter – wasted application